Original Paper

Caries Research

Caries Res 2014;48:208–213
DOI: 10.1159/000354838

Received: March 12, 2013
Accepted after revision: August 2, 2013
Published online: January 29, 2014

Should Cavitation in Proximal Surfaces Be Reported in Cone Beam Computed Tomography Examination?

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Key Words
Bitewing · Cone beam computed tomography · Dental caries diagnosis

Abstract
Aim: A clinical study was done to assess the clinical diagnostic accuracy of cone beam computed tomography (CBCT) in detecting proximal cavitated carious lesions in order to determine whether cavitation should be reported when a CBCT examination is available. ***Materials and Methods:*** 79 adjacent proximal surfaces without restorations in permanent teeth were examined. Patients suspected to have carious lesions after a visual clinical and a bitewing examination participated in a CBCT examination (Kodak 9000 3D, 5 × 3.7 cm field of view, voxel size 0.07 mm). Ethical approval and informed consent were obtained according to the Helsinki Declaration. Radiographic assessment recording lesions with or without cavitation was performed by two observers in bitewings and CBCT sections. Orthodontic separators were placed interdentally between two lesion-suspected surfaces. The separator was removed after 3 days and the surfaces recorded as cavitated (yes/no), i.e. validated clinically. Differences between the two radiographic modalities (sensitivity, specificity and overall accuracy) were estimated by analyzing the binary data in a generalized linear model. ***Results:*** For both observers, sensitivity was significantly higher for CBCT than for bitewings (average difference 33%, $p < 0.001$) while specificity was not significantly different between the methods ($p = 0.19$). The overall accuracy was also significantly higher for CBCT ($p < 0.001$). ***Conclusion:*** CBCT was more accurate in detecting cavitation in proximal surfaces than bitewing radiographs; therefore a CBCT examination performed for other clinical applications should also be assessed for proximal surface cavities in teeth without restorations, and when detected, this pathology must be part of the dentist's report.

Cone beam computed tomography (CBCT) is the most recent modality in the imaging armamentarium for advanced diagnosis of various dentomaxillofacial pathologies [Scarfe and Farman, 2008]. Reporting on a CBCT examination forms an important part of the duties of the dentist who has conducted the examination, and this can be quite time-consuming. Neglect on the part of the clinician to report findings in the CBCT volumetric dataset may be seen as an incomplete CBCT report. In many countries, radiation authorities have issued guidelines that a report must always follow a CBCT examination; e.g., the American Academy of Oral and Maxillofacial Ra-

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0008–6568/14/0483–0208$39.50/0

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diology states that the responsibility of systematically reviewing the entire CBCT image dataset for disease lies with the clinician [Carter et al., 2008]. Therefore, it is important to provide evidence for which pathologies should be reported in the CBCT dataset.

Dentists currently diagnose carious lesions using visual, tactile and radiographic examination, and bitewing radiography has been the conventional adjunct to clinical examination for detecting proximal carious lesions [Ricketts et al., 1995; Pitts, 2001]. Recently, the accuracy of CBCT for detecting demineralization in proximal as well as occlusal surfaces has been explored in in vitro studies. Akdeniz et al. [2006] found that the depth of lesions imaged with CBCT (3D Accuitomo) corresponded well with that observed in histological sections. Tsuchida et al. [2007], Senel et al. [2010] and Haiter-Neto et al. [2008] found no benefit in overall accuracy for CBCT over intraoral film and digital receptors for detecting demineralization in proximal surfaces, while Young et al. [2009] concluded that sensitivity for lesions extending into dentin was higher with CBCT than with an intraoral digital receptor. For demineralization in occlusal surfaces, however, a very high percentage of false-positive decisions has been reported with CBCT imaging, possibly due to streak artifacts [Young et al., 2009] in the image from the thick crown enamel. From this study, it may be concluded that occlusal demineralization should not be reported from a CBCT examination.

The recent consensus that only cavitated carious lesions need to be operatively restored emphasizes the shift of focus from detecting incipient carious demineralization to cavitated lesions [Kidd and Fejerskov, 2004]. One in vitro study has assessed the validity of CBCT in differentiating cavitated proximal lesions from non-cavitated demineralization and concluded that CBCT was much more valid in detecting surface cavitation, thus having an impact on treatment decision [Wenzel et al., 2013]. Since previous studies on the efficacy of CBCT were all performed in vitro under 'ideal' or well-controlled experimental settings, they are compounded with limitations. Therefore, the findings from in vitro models need to be tested in clinical settings before any recommendations for reporting on CBCT examinations in patients can be forwarded [Young et al., 2009; Rathore et al., 2012].

The aim of this study was to assess the clinical diagnostic efficacy of CBCT in detecting proximal cavitated carious lesions and compare this with bitewing radiography as the reference method in order to determine whether such lesions can be detected and should be reported when a CBCT examination is available.

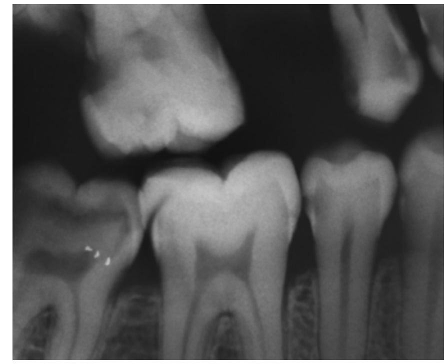

Fig. 1. Proximal lesion scored as cavitated involving the dentin on the distal surface of the mandibular second premolar and lesion scored as non-cavitated on the mesial surface of the mandibular first molar.

Materials and Methods

This study had ethical approval from the institutional review board of Nair Hospital Dental College, Mumbai, India (approval number: 007/EC/2012). Ethical approval was given on the basis that caries lesions along with periodontal disease being a common oral finding may be reported in a CBCT examination. Subjects who accepted to participate in the study and were over 18 years of age signed an informed consent form written in the local language. Ethical approval and informed consent were obtained according to the Helsinki Declaration. The consent form informed the patient of the different aspects of hazards of radiation as well as the possibility of tenderness associated with placement of a tooth separator. The patients were allowed to speak to the principal investigator in case of any apprehension. They could opt out of the study at any point.

Patients and Initial Clinical Examination

A total of 34 subjects were recruited for the study. An equal number of male and female patients with age ranging from 18 to 63 years (mean 36.76 years) were included. Initially, patients who were suspected to have carious lesions at two adjacent surfaces after a visual clinical examination (discolorations observed), and who then required a bitewing examination, were invited to participate in the study. Exclusion criteria were patients who had restorations in the teeth to be examined (restorations in neighboring teeth were allowed, and no surface was excluded in spite of some streaking/beam hardening effect from the adjacent restoration) and surfaces with large cavitations and gross lesions easily observed during the conventional clinical examination.

After the initial clinical examination, 80 two-by-two adjacent surfaces in the upper and lower permanent premolar/premolar, premolar/molar and molar/molar interfaces were included. Six patients contributed with two pairs of surfaces. The patients were examined by bitewing radiography and CBCT. This was done on the same day as the initial clinical examination after patient acceptance.

Bitewing Examination

Bitewing radiographs (fig. 1) were recorded on size 1 film (Ektaspeed Plus, Eastman Kodak, Rochester, N.Y., USA) using an interproximal device holder (Bluedent India, Chennai, India). A

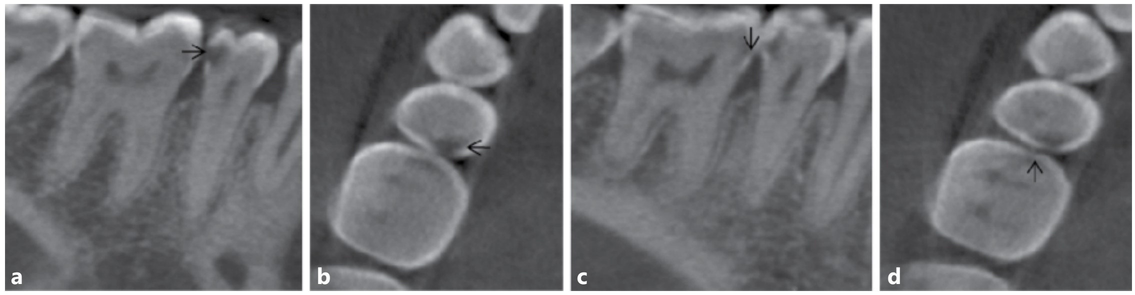

Fig. 2. The same proximal lesions as seen in figure 1 displayed in sagittal and axial CBCT sections confirming cavitation on the distal surface of the second premolar (**a**, **b**), but scored also as cavitation on the mesial surface of first molar (**c**, **d**).

Sirona dental unit (Heliodent Plus, Sirona Dental, Salzburg, Austria) operated at 65 kVp, 7.5 mA and 0.21 s, was used to expose the films with the beam aiming perpendicular to the interproximal space between the teeth in question. The unit had a 0.7 mm focal spot and a 2 mm aluminum filter. The exposed films were processed in an automatic processing machine at 27°C with a 4.5 min processing cycle. The radiographs were viewed using a ×2 magnification with a constant light intensity.

CBCT Examination

CBCT examination (fig. 2) was performed using a Kodak 9000C 3D unit (Carestream Health Inc., Rochester, N.Y., USA) operated at 80 kVp, 5 mA, 5 × 3.7 cm field of view, voxel size 0.07 mm and an image acquisition time of 10.8 s. One quadrant image rotation was used. The equivalent dose was <38 μSv per quadrant. The acquired data were reconstructed with a 0.2 mm section interval and thickness. Observers used the Digital Image Communication in Medicine (DICOM) software to evaluate the reconstructed image sections in three planes. Radiographers who were not part of the study performed the bitewing and CBCT radiographic examinations.

Clinical Validation

Patients were thereafter subjected to wearing an orthodontic elastic separator (American Orthodontics Corp., Sheboygan, Wisc., USA) placed between the two suspected surfaces in question (fig. 3). The six patients who contributed with two pairs of surfaces wore two separators. These were not in the same side of the mouth.

The clinical validation was performed by a separate observer (senior clinical teacher) not involved in the radiographic assessments. After 3 days, the tooth separator was removed, leaving an interproximal space of approximately 0.5 mm (fig. 4). The interproximal space was cleaned with Superfloss (Oral-B Laboratories, Isleworth, UK), washed and dried. The visual examination was recorded under relative saliva isolation (with a cotton roll) and with the aid of a blunt explorer probe and a flat dental mirror. The probe was used for tactile evaluation of the surface without pressure. The clinical observer recorded the two adjacent tooth surfaces separately as cavitated (yes/no). The patients who had cavitated lesions were offered operative treatment.

Radiographic Assessment

Two observers (both experienced radiologists) with at least 5 years of experience in reading bitewing and CBCT images individually assessed the images from both modalities at different

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Fig. 3. Orthodontic separator placed between two suspected surfaces.

Fig. 4. Separation between suspected surfaces after removal of the separator revealing cavitation on the mesial surface of the first molar.

times. Both observers assessed the bitewing first followed by the CBCT. The observers were provided with a training session before assessments. They were not aware of the aim of the study, nor were they informed of the suspected cavitation prevalence rate of the study population. All CBCT images were obtained in a DICOM format and transferred to a separate workstation. All observations were done in a quiet windowless room with dimmed lighting. CBCT images were viewed on HP Compaq LE 1911, 19″ VGA LCD display (Hewlett Packard Company, Palo Alto, Calif., USA) at a 1,280 × 800 resolution using the Kodak dental imaging software (version 6,12,10,0, copyright Carestream Health Inc.). Observers were allowed to use two-fold magnification and modify screen brightness. For the CBCT images the observers could scroll and view all sections in sagittal, coronal and axial planes.

In both bitewing and CBCT images each surface was scored as cavitation yes/no. The complete extent of the lesion on one surface could not be assessed because of a scratch artifact; this surface was therefore omitted from all further analyses.

Table 1. Percentage of sensitivity, specificity and overall accuracy for each imaging method: bitewing and CBCT for observer 1 and observer 2

	Observer 1		Observer 2	
	bitewing	CBCT	bitewing	CBCT
Sensitivity	46	75	42	79
Specificity	84	77	87	77
Accuracy	61	76	59	78

Table 2. Difference (95% confidence interval) in sensitivity, specificity and overall accuracy between the imaging methods: bitewing vs. CBCT for observer 2 vs. observer 1

	CBCT vs. bitewing	Obs. 2 vs. obs. 1
Sensitivity	33 (20;47)*	1 (–5;6)
Specificity	–8 (–20;4)	2 (–5;8)
Accuracy	17 (7;28)*	1 (–3;5)

* p < 0.001.

Table 3. CBCT examinations in which artifacts were recorded by observer 1 and 2

Artifacts	Observer 1	Observer 2
Present	13	16
Absent	66	63

Kappa = 0.705.

In each CBCT examination as a whole the observers also assessed the presence of streak artifacts (yes/no) arising from neighboring tooth restorations.

Data Analysis

Statistical analyses were performed by transferring all the data on Microsoft Excel 2003 software (Microsoft Corporation, Redmond, Wash., USA) and using Stata version 12.1 for analysis.

For each observer and each radiographic modality, the sensitivity, specificity and overall accuracy (true positives and true negatives/all scores) were computed by comparing the radiographic scores to the clinical validation. The difference in sensitivity, specificity and accuracy was estimated by analyzing the binary data, assuming additive effects of observer and modality in a generalized linear model using an identity link function. The correlation within surfaces was adjusted for by applying robust standard errors. Pairwise comparisons between modalities were performed by Wald tests. The level of statistical significance was $p < 0.05$.

Interobserver agreement for the presence of streak artifacts was expressed by kappa statistics.

Results

According to the clinical examination immediately after removal of the tooth separators, 48 (61%) of the surfaces were cavitated and 31 (39%) were non-cavitated.

Table 1 presents percentage of sensitivity, specificity and overall accuracy for recordings in bitewings and CBCT images for each observer. For both radiographic observers, bitewing had low sensitivity but higher specificity in detecting cavitated proximal lesions, while CBCT had both high sensitivity and specificity. Table 2 presents the difference with confidence intervals in sensitivity, specificity and overall accuracy between the imaging methods and between the radiographic observers. Sensitivity was significantly higher for CBCT (average difference 33%, confidence interval 20;47, $p < 0.001$); however, specificity was not significantly different between the methods ($p = 0.19$). This means that no more false-positive scores were made with CBCT than with bitewing radiography. Overall accuracy was also significantly higher for CBCT (average difference 17%, confidence interval 7; 28, $p < 0.001$). There were no significant differences between the two observers for any parameter (tables 1, 2).

The number of CBCT examinations in which artifacts were recorded is shown in table 3 for observer 1 and 2 separately. The interobserver agreement was moderate (kappa = 0.705).

Discussion

The objective of this study was to assess whether proximal cavitated carious lesions could be detected and therefore should be reported in a CBCT examination. The working hypothesis of this study was that cross-sectional imaging would provide a higher accuracy than bitewing radiography for detecting cavitation based on the results of a recent in vitro study [Wenzel et al., 2013].

No previous in vivo study has determined the efficacy of CBCT to display clinical cavitation in proximal surfaces. It is of the outmost importance that in vitro experiments are followed by clinical studies to obtain a higher level of evidence for the diagnostic task in question. In clinical studies, the challenge may be to obtain a validation for the radiographic findings that is meaningful to the clinician. For detection of cavitation in proximal surfaces, the temporary tooth separation technique has been proposed to overcome the difficulty of visually examining proximal surfaces in the clinic. Studies have compared direct visual inspection after temporary tooth separation to conventional visual inspec-

tion and revealed a much higher detection rate of cavitated lesions after temporary tooth separation [Pitts and Longbottom, 1987; Hintze et al., 1998], the tooth separation method has therefore been stated to be an effective method to validate the radiographic diagnosis. In our study, all interproximal spaces were opened after tooth separation, however to a varying degree, and the average space provided was 0.5 mm. Using this validation method, the accuracy for detecting cavitation was quite high for CBCT images; the high sensitivity was followed by a somewhat, but not significantly, lower specificity than was obtained with bitewing radiography. Bitewings on the other hand had a low sensitivity. A high agreement in all accuracy parameters between the two observers' assessments with the two radiographic modalities also means that the results were reproducible. Our working hypothesis thus holds true.

It could be speculated that the spatial resolution and resultant detail perception in CBCT patient images would be considerably less than in previous in vitro CBCT data [Wenzel et al., 2013]. In dental practice a major fraction of the patients could have metallic tooth restorations, implants or endodontic restorative materials that may cause beam hardening artifacts simulating carious lesions in the CBCT images. Such artifacts may create streaks of bright and dark bands and noise in image reconstructions that can project over adjacent teeth. In particular, dark bands may convey the false impression of a lesion. Patient movement similarly may decrease structure sharpness and definition, further impeding caries lesion diagnosis [Scarfe and Farman, 2008; Spin-Neto et al., 2013]. In our study, none of the test surfaces had restorations, but many of the neighboring teeth did. In spite of some beam hardening effect all surfaces were still included in the study. The observers noted whether streak artifacts were seen in the CBCT sections, and a little over 20% of the scans were scored to possess artifacts, which however did not prevent the observers from being able to score the surface. It may be speculated that the differences in image quality between teeth in patients and teeth in vitro may partly explain the differences in false-positive detection rate of cavitated lesions in the previous in vitro [Wenzel et al., 2013] and the present study.

It has previously been suggested to use small voxel sizes to detect proximal lesions in CBCT sections [Haiter-Neto et al., 2008], thus in the present study a 0.07 mm voxel size and a small field of view was used. The effective dose for a small field of view CBCT ranges from 8 to 40 μSv [Hirsch et al., 2008]. The effective dose for conventional imaging is in the range of 1–8.3 μSv for an intraoral exposure and 35 μSv for a full-mouth radiographic survey with rectangular collimation [Ludlow et al., 2006, 2008]. Moreover, a CBCT examination is resource-demanding and much more expensive than bitewing radiography. It is therefore critical that the potential patient benefit from a CBCT examination be balanced against the risk of exposure to ionizing radiation. Taking these factors into account, we cannot recommend that CBCT is used as the routine, primary radiographic examination for detection of caries lesions, even though the accuracy was higher for lesion cavitation than was bitewing imaging.

'Failure to diagnose' is however a relatively common matter in legal cases against dentists. It has therefore been emphasized that all healthcare professionals, regardless of their specialization, should be trained to recognize pathology in the head and neck region [Epstein et al., 2009]. With the mushrooming of short CBCT courses for dental practitioners, it is anticipated that more general dentists will be working with the CBCT, particularly in countries where dentomaxillofacial radiology is not a recognized specialty. This will also be compounded by the ubiquitous presence of CBCT in tertiary care centers. A cavitated proximal surface is a pathologic finding which should be treated operatively. It can therefore be concluded that if a CBCT examination is available for any other application like implant site evaluation, tooth impaction or endodontic applications, it would be the responsibility of the oral radiologist or clinician who views the CBCT sections to report also on proximal carious lesions in teeth without restoration and to state whether or not the lesion is cavitated.

In conclusion, CBCT examination was significantly more accurate than bitewing radiography for detecting cavitated proximal carious lesions in posterior teeth without restorations.

Disclosure Statement

The authors of this paper do not have any conflict of interest to declare.

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